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A NEW FUZZY LOGIC CONTROL METHOD IN WIND ENERGY CONVERSION SYSTEM FOR STAND-ALONE USING MATLAB/SIMULINK

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ABSTRACT

This articlepresents the simulation of a wind energy system for stand-alone using MATLAB/Simulink. This system is composed of five parts: wind turbine (WT), permanent magnet synchronous generator (PMSG), rectifier, DC/DC Boost converter, and resistive load. In order to track maximum possible power,a novel maximum power point tracking(MPPT) controller based ona fuzzy theory is designed. The advantage of this method is notcompulsory to measure generator speed and wind speed. The results in simulation using MATLAB/Simulink show that our controller achieves good performances whatever the climatic variations or load.

KEYWORDS: Wind Energy Conversion System, Stand Alone; Maximum Power Point Tracking; Mppt;Fuzzy Logic Control; Flc;Permanent Magnet Synchronous Generator & PMSG

Original Article

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INTRODUCTION

Due to population growth, urbanization, and economic development, global energy demand continues to increase, especially for developing countries. Today, the production of electrical energy is based largely on fossil resources such as oil, gas, and coal. However, these forms of energy are constantly diminishing and have harmful effects on the environment. For these reasons, in order to meet energy needs and minimize environmental impacts, the exploitation of renewable energies is a promising avenue.

In this day, wind energy has become one of the most emerging renewable energy sources. Electricity generated from wind power has increased significantly over the past three decades.In Vietnam, more than half a million people do not have access to electricity. They are mainly in mountainous regions or on islands. However, this country has great potential in renewable energies especially wind energy. In this context, a small wind electric system is the most suitable for ruralareas that are not served by the national electricity grid.

Wind energy conversion system using PMSG is rapidly growing because of higher reliability, less maintenance and more effective. A system of variable speed PMSG is more flexible because it can adapt to wind variations [1].

There is only one rotor speed for each wind speedwhich generates maximumpower from the wind turbine. This optimal rotor speedcan be obtained by using MPPT algorithm. Up to now,many methodsof MPPT are proposed[2]–[5]. Two categories are the most popular. The first categoryutilizesthe knowledge of turbine parameters (power curves, power coefficient and torque). The second category is based on iterative research. In this article,a novel MPPT controller based ona fuzzy theory is proposedto track the maximum point.The maximum power can be obtained by controlling the Boost converter duty cycle.There is no need to measure generator speed

and wind speed in this method.

WIND TURBINE SYSTEMS

The overall system configuration is shown in Figure 1. PMSG is directly coupled to awind turbine. An uncontrolled rectifier is between the wind generator and DC link because the generated voltage from PMSG is AC voltage which cannot directly supply the DC link. A Boost converter is used to adjust the rotor speed by controllingduty cycle (D)soto achieve the maximum power.

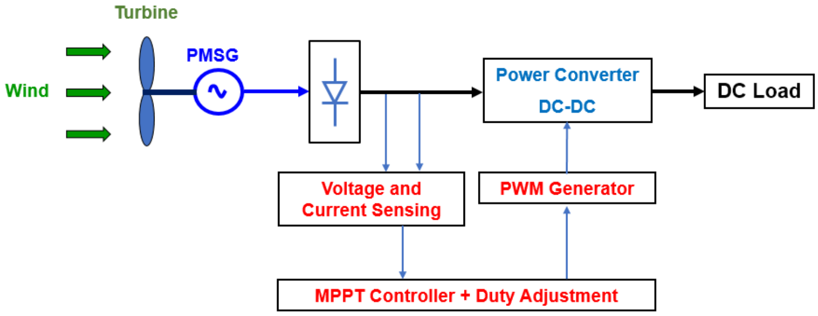

Figure 1: Wind Turbine Configuration.

1.1. Wind Turbine Modeling

For a variable speed wind turbine, the power captured from the wind is given by[6], [7] :

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R_{blade}^2 v_{wind}^3 \,. \qquad (1)$$

where ρ is the air density (kg/m^3); $R_{turbine}$ is the radius of the turbine blade (m); v_{wind} is the wind speed (m/s); C_p is the turbine performance coefficient; λ is tip speed ratio; β is blade pitch angle (deg).

Based on equation (1), the maximum output power of a wind turbine is obtained whenthe turbine performance coefficient C_p should be optimized. This coefficient is a nonlinear function and depends on many factorssuch as:number of blades, geometry of the turbine blades, and pitch. Theoretically, the maximum value of C_p is 0.593 and it is called the Betz limit. However in reality this maximum value is around0,4…0,5 due to losses[7].

The tip-speed ration (TSR)λ is the ratio of the turbine angular speed and wind speed:

$$\lambda = \frac{\Omega R_{turbine}}{v_{wind}} \,. \qquad (2)$$

where Ω is the angular shaft speed (rad/s)

The turbine mechanical torque can becalculated:

$$T_m = \frac{P_m}{\Omega} = \frac{1}{2} \frac{C_p(\lambda, \beta) \rho_{air} \pi R_{blade}^2 v_{wind}^3}{\Omega} \,. \qquad (3)$$

As we noted that the power captured from the wind is a function of the tip-speed ratio. So base on equation (2)it depends on wind velocity and rotational speed.If the tip-speed ratio λ is attainedthe optimal value,when the turbine performance coefficient C_p achieves also its maximum value $C_{pM}=C_p(\lambda_{opt})$.

Hence the maximum output power available from the WT is:

$$P_m^{opt} = \frac{1}{2} C_{pM} \rho \pi R_{blade}^2 v_{wind}^3 . \tag{4}$$

When the tip-speed ratioachievesthe optimal value, the optimal rotor can be expressed by:

$$\lambda^{opt} = \frac{\Omega R_{blade}}{v_{wind}} \Rightarrow \Omega^{opt} = \frac{\lambda^{opt} v_{wind}}{R_{blade}} . \tag{5}$$

As shown in Figure 2, there is only one optimal rotor speed for each wind speed,which leads to extract the maximum power.

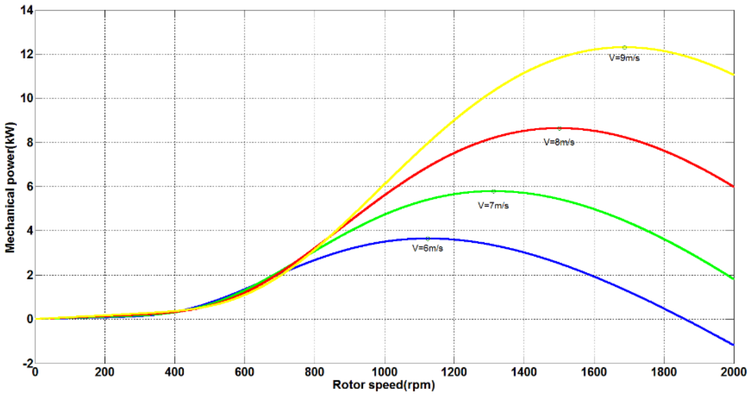

Figure 2: Output Power for Different Values of Wind Speed.

1.2. PMSG Modeling

The voltage equations of a PMSG in the Park's system are[1], [8]:

$$V_d = -R_S i_d - L_d \frac{di_d}{dt} + \omega L_q i_q . \tag{6}$$

$$V_q = -R_S i_q - L_q \frac{di_q}{dt} - \omega L_d i_d + \omega \lambda_m . \tag{7}$$

The electromagnetic torque produced by the PMSG is:

$$T_e = \frac{3}{2} p[(L_d - L_q) i_q i_d - \lambda_m i_q] . \tag{8}$$

$$\Omega = p\omega . \tag{9}$$

where p is the number of pole pairs; $\lambda_m$is the magnetic flux; $L_d$is the direct axis inductance; $L_q$is the inductance in quadrature; $R_s$is the stator resistance; ω is the electrical angular frequency.If the rotor is cylindrical, $L_d \approx L_q \approx L_s$ so:

$$T_e = -\frac{3}{2} p\lambda_m i_q \,. \tag{10}$$

The torque equation and the induced voltage equation are as follows:

$$T_e = k_T I_a \,. \tag{11}$$

$$E = k_E \omega \,. \tag{12}$$

where I_a is the stator current, k_T and k_E is the torque and voltage coefficient.

Another way:

$$E^2 = V_{WT}{}^2 + (I_a L_s \omega)^2 \,. \tag{13}$$

where $V_{WT}$is the generator phase voltage*;* $L_s$is the inductance of the generator.

1.3. Rectifier

The PMSG is connected to an uncontrolled diode rectifier and Boost converter to supply the DC-linkas shown in Figure 1.Proposed MPPT controller for PMSG driven wind turbine.

1.4. Principle

Based on Figure 2, maximum power points are identified when :

$$\frac{dP_{WT}}{d\Omega} = \frac{dP_{WT}}{dV_{WT}} \frac{dV_{WT}}{d\Omega} = 0 \cdot \tag{14}$$

On other hand, rotor speed is proportional to the generator phase voltage in a permanent magnet synchronous generator [1], so :

$$\frac{dV_{WT}}{d\Omega} > 0 \,. \tag{15}$$

Hence we have :

$$\frac{dP_{WT}}{d\Omega} = 0 \Leftrightarrow \frac{dP_{WT}}{dV_{WT}} = 0 \cdot \tag{16}$$

Our method based on principle:

- If $dP_{WT}/dV_{WT}=0$, we achieve the maximum output power.
- If we are in the region Up-hill($dP_{WT}/dV_{WT}>0$), the controller should decrease the duty cycleto achieve the maximum power point(MPP).

- If we are in the region Down-hill($dP_{WT}/dV_{WT}<0$), the controller should increase the duty cycle to achieve the maximum power point (MPP).

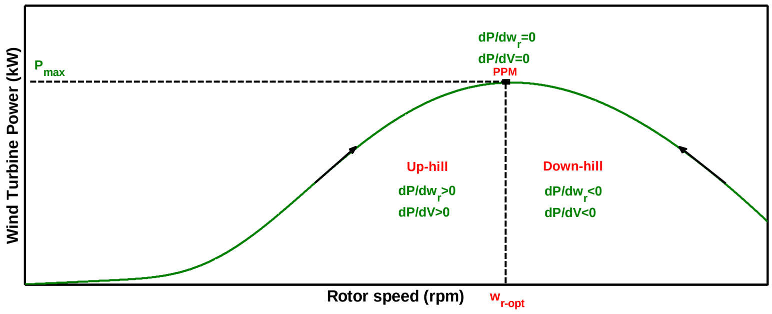

Figure 3. MPP Tracking.

1.5. Fuzzy Control Logic

Fuzzy logic controller consists of four major elements as shown in figure 4.

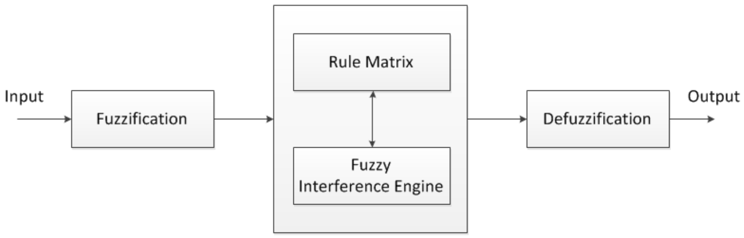

Figure 4: Fuzzy Logic Controller.

The proposedalgorithm is designed to control the Boost converter duty cycleto reach the optimal rotor speed, thus maximum output power from the wind turbine.In this article, we present a new MPPT fuzzy logic controller by using only one input: (dP_{WT}/dV_{WT}) and output is Boost converter duty cycle (D). The system can improve the response time compared to using the traditional P&O method because depending on the region and position of the operating point, the value of outputΔD is chosen as small or big. For example, if the operation point is far from PPM, the value of output ΔD is big.

Input and Output Variables: The output of the controller is given as:

$$D(n)=D(n-1)+\Delta D(n) \tag{17}$$

Fuzzification: We use nine membership functions.The linguistic term used in this controller are:dP/dV [VeryNega, BigNega, MediNega, Negative, Zero, Positif, MediPosi, BigPosi, VeryPosi]

Inference: The method of fuzzy inference rules is the min-max inference.Table 1 below shows the chosen rules.

Defuzzification: In this article, thedefuzzification method is the center of gravity.

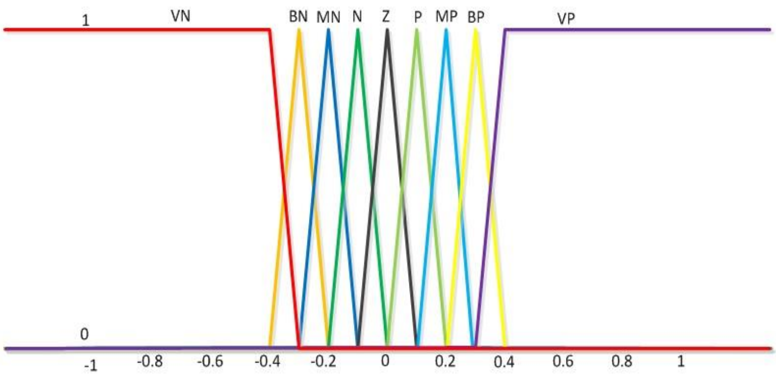

Figure 5: Memberships Functions of FLC.

Table 1:Rules of ΔD Simulation and Results

dP/dV	ΔD (%)
VeryNega	2.5
BigNega	0.7
MediNega	0.1
Negative	0.05
Zero	0
Positive	-0.05
MediPosi	-0.1
BigPosi	-0.7
VeryPosi	-2.5

1.6. Simulation

The WECS is designed and modeled in MATLAB/Simulink environment as shown in figure 6.

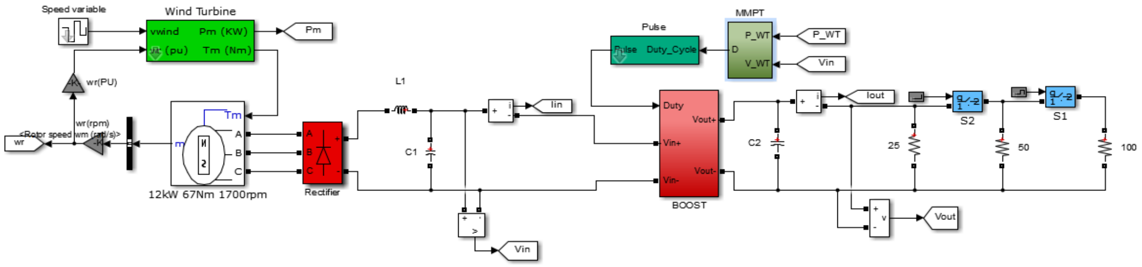

Figure 6: Implemented inMATLAB Simulink.

In order to test the proposed controller in various conditions, wind speed and load demand are varied as shown in Figure 7.

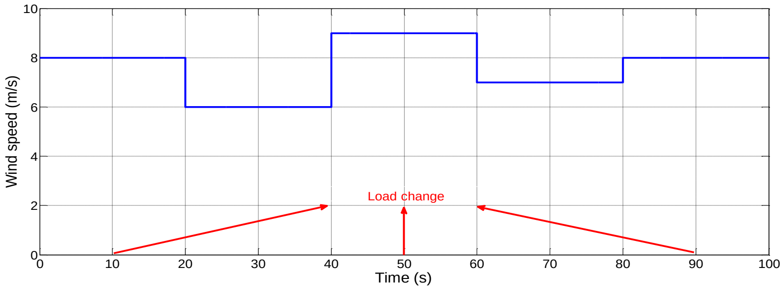

Figure 7: Variation Condition.

MPPT method using Fuzzy logic controller is shown in the Figure 8.

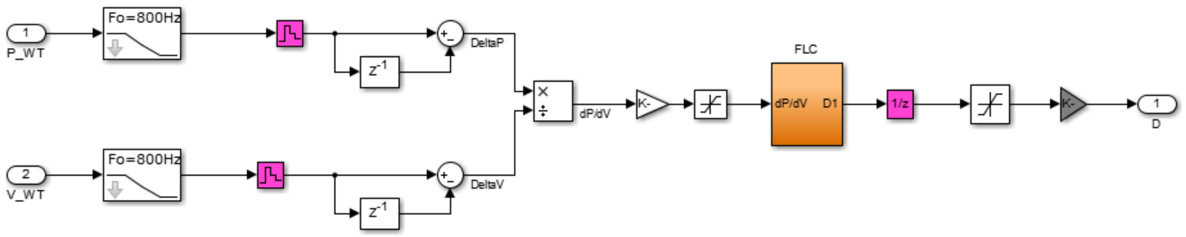

Figure 8: MPPT Method Using FLC.

1.7. Results

The simulated results of WECS under variation of wind speed and load are shown below.

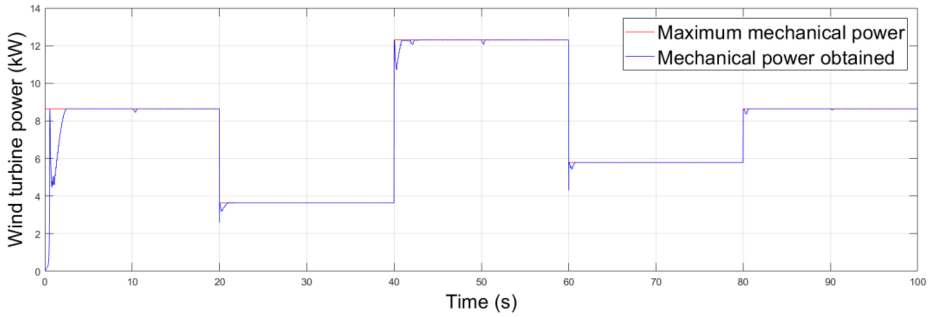

Figure 9: Wind Power.

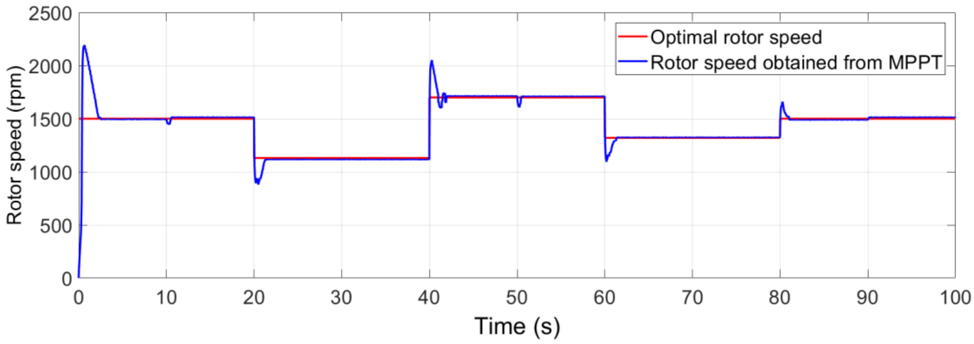

Figure 10: Rotor Speed.

According to the optimal power curve (figure 2), the optimal rotor speed at 8m/s is 1500 rpm and the maximum power output is 8.64 kW. In our simulation, wind speed is about 8m/s in the first twenty seconds. The proposed controllerhas adjusted the value D to reach the rotor speed optimal. After 3s, the rotor speed is 1494 rpm. The power output is 8.638 kW. Then wind speed goes down to 6 m/s in the next 20 seconds, the operating point of systems move to the new MPP as shown in Figure 9 and 10.

The other test is simulated when the wind speed varies as shown in figure 7. figure 10 shows that the rotor speed adjusts following the changes in the wind speed to obtain the desired output.

Using the proposed controller, WECS also operate close to MPP when load demand change as shown in Figure 9 and 10. The response time is approximately 1s for each change of load demand.

CONCLUSIONS

This article proposes a novel MPPT algorithm using fuzzy logic control for a PMSG drive WECS. By using only one input the structure of the controller, the results of the simulation showed that our controller can track MPPT and has good performance, small oscillation, andfast response under condition variations.

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